Endoscopic Shearography Nondestructive Evaluation of Lined Pressure Vessels

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Composite pressure vessels and fuel lines are being developed for use in advanced propulsion systems. To prevent leakage of fuel or oxidizer, composite tanks may be lined with a thin layer of metal or polymer. Several nondestructive evaluation (NDE) techniques have been developed which are highly capable of detecting damage in the outer composite structure. Among these are ultrasonics, thermography, and shearography. However, methods to detect an unbonded internal liner have not existed. Ultrasonic methods are a possibility, but remain limited if the liner is very thin or the case is thick or porous. Shearography detects slight changes in a surface shape when some stressing state is imposed and is very successful at detecting unbonds in paints, coatings and thin bonded layers. Shearography systems consist of specialized illumination and imaging optics as shown in figure 75. Due to space restrictions, insertion of the optical head or camera into the pressure vessel for inspection of the bond line integrity between the core or liner and the outer casing may be impossible. In some cases, personnel may be required to crawl inside the structure, which presents several safety risks. The need was thus identified for an endoscopic inspection system using borescopes or fiber optics to illuminate and view the inside of restricted spaces with shearography optics. Application examples are examining lined fuel tanks through access covers or drain ports and inside lined fuel or oxidizer lines. To this end a prototype borescope shearography system and method was developed to examine the inside of confined spaces with limited access.

Electronic shearography images a coherently illuminated object through an image shearing lens to produce an interference fringe pattern. The boundaries between light and dark fringes represent contours of constant change in surface slope due to some form of excitation. The MSFC NDE Branch electronic shearography (ES) system was modified for this study. This device utilizes a modified Michelson interferometer as an image shearing device, as shown in figure 75. A frequency doubled Nd:YAG-pumped diode laser ($\lambda = 532$ nm) is used as a source of coherent illumination, the beam of which passes through a beam expanding lens pair and a beam steering wedge to produce a laser speckle pattern on the surface of the test article. The light reflected from the object is collected by a telephoto lens, which provides a variable field of view, and is imaged onto the sensor

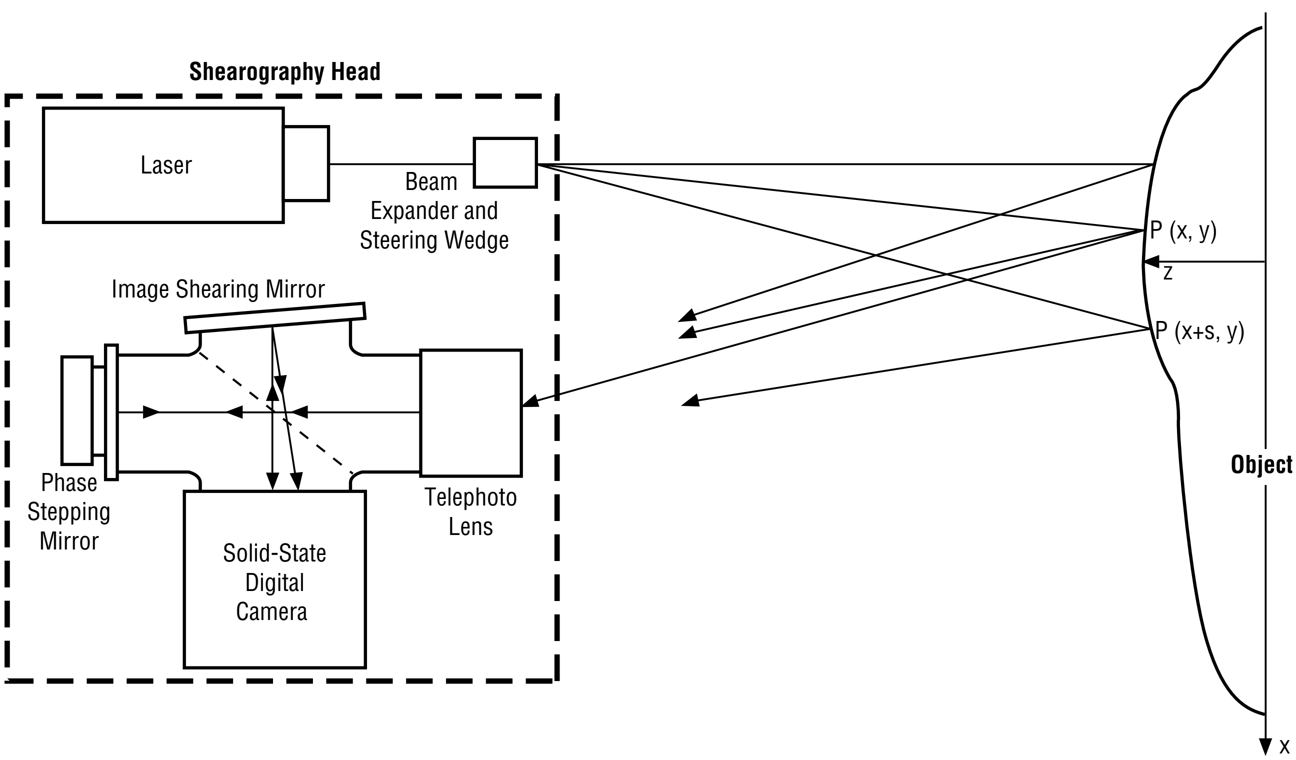

FIGURE 75.—Shearography optical system.

array of a CCD camera through the shearing interferometer.

Each ray passed through the telephoto lens is separated by the beam splitter into a reference beam and a sheared beam. The reference beam passes straight through the beam splitter, reflects from a phase stepping mirror back along its previous path, and is reflected from the back of the beam splitter toward the sensor array. The sheared beam is reflected from the front of the beam splitter toward the image shearing mirror, reflected back again at a tilted angle, then passed through the beam splitter toward the sensor array. The sheared beam is incident on the sensor array at a point which is shifted, or sheared, from the reference beam. Each point on the surface of the object is thus imaged to two separate pixels on the camera sensor array. A more complicated reverse ray trace shows that, similarly, a single pixel on the camera sensor array images two sheared points on the surface of the object. Assuming a planar object, all points in the image are sheared by the same lateral distance, referred to as the image shearing distance, *s*. The sensitivity of the device is proportional to *s* and thus related to the angle at which the image shearing mirror is tilted. By varying the tilt angle and direction of the image shearing mirror, the operator may adjust the sensitivity of the device to suit the structure being evaluated and the type of excitation being applied.

In the static test mode, sheared images are digitally acquired before and after some form of excitation is applied to the test article. The intensity recorded on each pixel is a function of the relative phase between the light rays reflected from the two corresponding points separated by in the direction of image shearing on the object surface, and thus a function of the relative slope across that interval of the image shearing distance. After the test object has been statically excited, typically by heating, cooling, or changing the pressure to which it is exposed, then a second sheared image is recorded. The digital frame subtraction of these two images results in a shearogram featuring a fringe pattern indicative of full-field values for the change in surface slope at each point on the object surface due to the excitation load.

Unlike electronic holography (EH), which produces fringe patterns indicative of object displacements toward the camera, ES senses changes in the slope of the surface of the object along intervals of the image shearing distance. That is, the fringes are produced by differences in motion toward (or away from) the camera between points separated by *s*. The ES technique is thus less sensitive overall than is EH. In addition, some EH techniques pass the reference beam directly from the laser to the sensor array inside an optical fiber and only the object beam reflects from the test article. Other EH techniques illuminate the test object with two coherent beams having almost entirely different optical paths in object space. The optical paths of the reference and sheared beam in ES differ only inside the interferometer. The ES technique is thus less sensitive to environmental effects (changes in vibration, temperature, etc.) than is EH. The ES apparatus does not require extensive environmental isolation, such as an vibration isolation optical table, and is regularly used for field evaluations.

A design was developed and tested for an endoscopic shearography method, as shown in figure 76. This design is a prototype which suggests the feasibility of a commercial apparatus and the supporting methodology. For this design, the shearing optics were removed from the ES system and a borescope was connected with the C-mount adapter to the shearography interferometer in place of the normal telephoto lens. This borescope will hereafter be referred to as the imaging borescope. A second borescope, the illumination borescope, was obtained and positioned parallel to the imaging borescope with the unexpanded laser beam entering the eyepiece. The beam expansion lens pair from the shearography head was positioned in front of the illumination borescope objective lens and adjusted such that the exiting laser beam was expanded to fill the imaging borescope field of view at a distance of 30 to 45 cm (12 to 18 in).

An experiment was conducted in which the endoscopic shearography design was positioned to image a flat test panel containing a programmed defect. This specimen was fabricated from graphite-epoxy with Teflon™ inserts of various sizes at various depths. For demonstration purposes a 4.45 cm (1.75 in) flaw was centered in the field of view at a distance of 30 cm (12 in) from the imaging borescope. The specimen was heated by a pair of 500 Watt quartz-halogen shop lamps from a distance of 20 cm (8 in) for 5 min causing the simulated defect to move differently

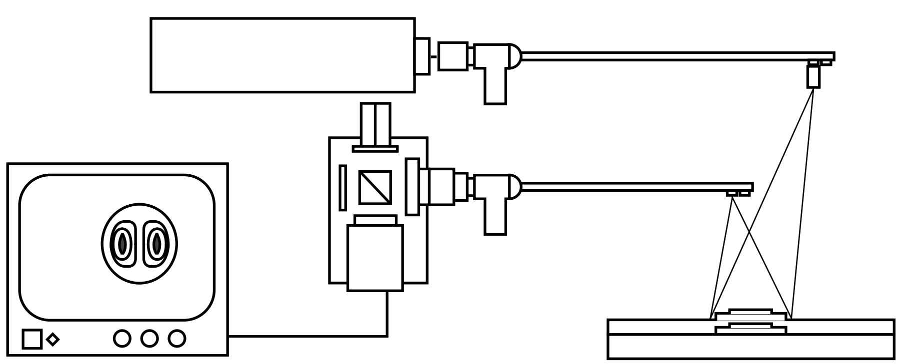

Figure 76.—Endoscopic shearography design with illumination and imaging borescopes.

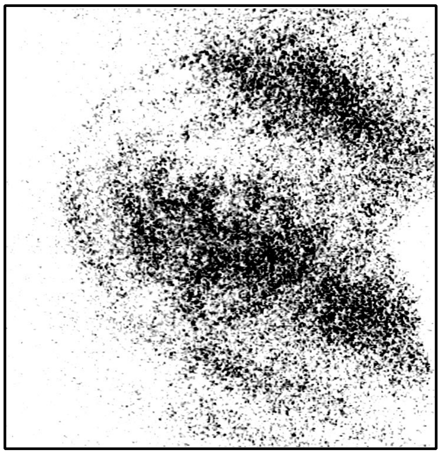

FIGURE 77.—Endoscopic shearography flaw indication.

than the surrounding area. Shearograms were recorded as the test article cooled after the lamps were turned off and moved away from the test setup. The flaw was successfully detected, as indicated by the circular fringe pattern in the shearogram of figure 77. The application of this device to inspect a lined fuel tank is shown as figure 78.

The feasibility and flaw detection capability of an endoscopic shearography apparatus has been demonstrated. This design utilizes commercially available borescopes for illumination and imaging. Endoscopic shearography allows the inspection of components such as lined fuel tanks which were previously difficult or impossible due to their closed structure. The method allows noncontact nondestructive evaluation without the need for personnel to enter the structure.

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University Involvement: Matthew Lansing/UAH Research Institute

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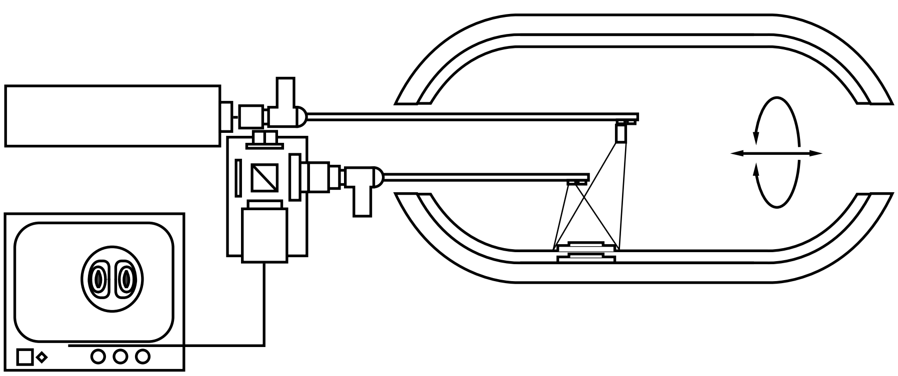

FIGURE 78.—Inspection of a lined fuel tank with final endoscopic shearography design.